An Evaluation of Select PEM Fuel Cell System Models

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Outline

- Initialization
- Evaluation criteria
- Overview of fuel cell models
- Evaluation of select fuel cell system models
- Concluding remarks

Initialization Process

Simulation objectives
Constraints
Type of problem
Issues to be addressed by simulation
Required level of detail
Available information
User level of knowledge

Evaluation Criteria

Dimension	State	System Boundary	Approach	Software
0-D 1-D 2-D 3-D	Steady-state Transient	Cell Fuel cell stack Fuel cell system	Theoretical Semi-empirical	Speed Accuracy Flexibility …

Evaluation Criteria

- Dimension
- State
- Model approach
- System boundary
- Details about electrochemistry, thermodynamics and fluid dynamics
- Validation
- Software details

Model Approach

Theoretical model

+ generic, flexible
-hard to get input data
-difficult to validate

or

Semi-empirical model

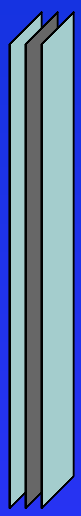
+ validated (to some extent)
- stack & operation conditions specific data

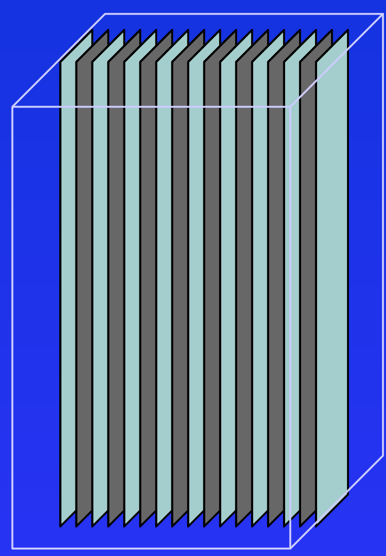
System Boundary

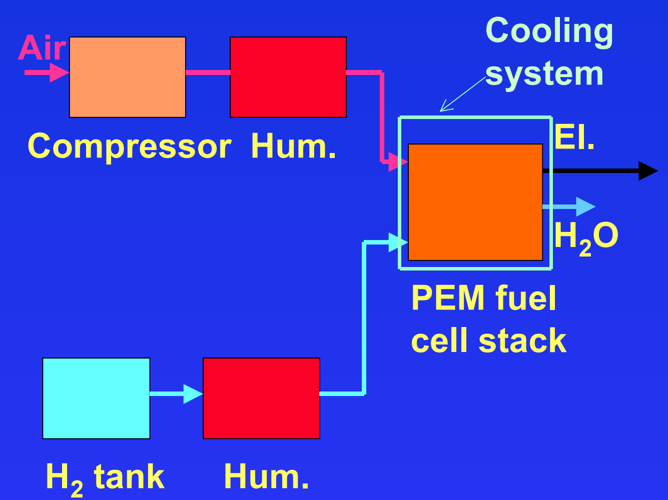
Cell

Stack

System



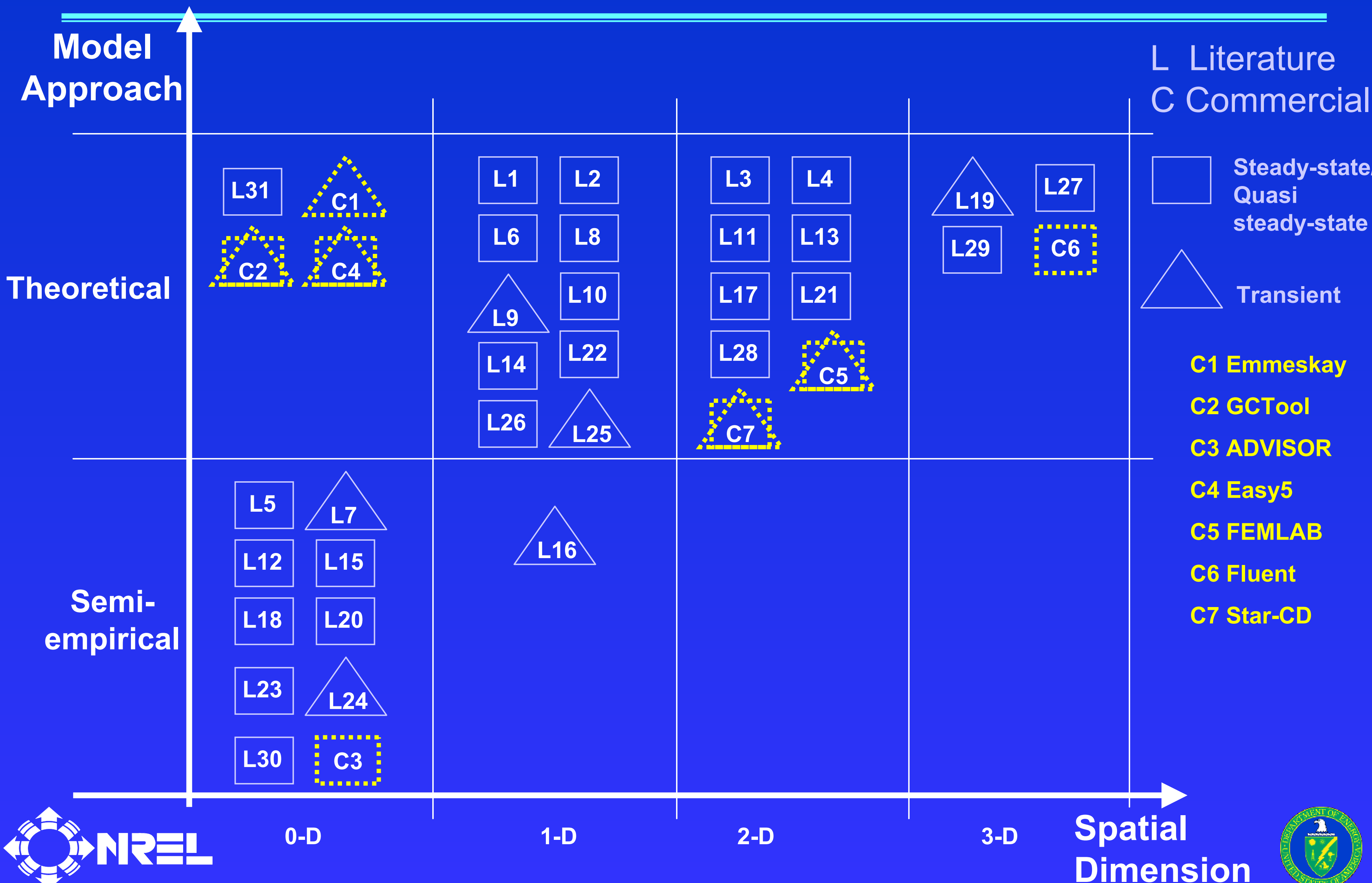




Software Criteria

- Speed
- Fixed/variable time step
- Real time
- Accuracy
- Flexibility
- Open source code/proprietary
- Graphical representation of model
- Post-processing of outputs
- Ease of learning

Overview of Fuel Cell Models



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NREL's Initial Decisions

- Simulation objectives
  - More detailed studies
    - parametric studies
    - component sizing
    - optimization
  - Integration into ADVISOR (Advanced Vehicle Simulator)
- Constraints
  - Time limited to 6 months
- Type of problem
  - A combination of discrete and continuous
- Issues to be addressed by simulation
  - Thermal and water management
  - Start-up requirements

NREL's Initial Decisions (cont'd)

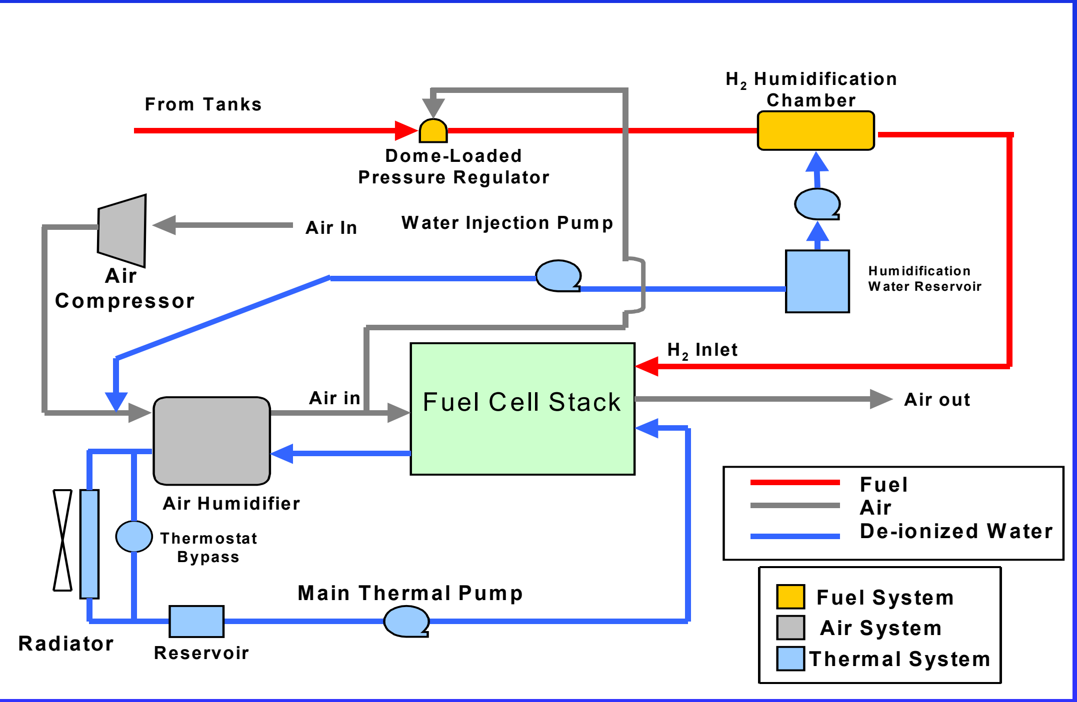
- Required level of detail
  - Zero-dimension
  - Steady-state or transient
  - Fuel cell system including auxiliary system components e. g. compressor, pumps, fans, etc.
  - Heat and mass balances
  - Accurate electrochemical fuel cell model
- Available information
  - Documentation from vendor, demonstration kit, etc.

NREL's Evaluation Criteria

- Based on MATLAB/Simulink
- Mass & energy balances for both fuel cell stack & system
- **Steady-state** **Dynamic**
  - **dynamic (transients in fuel cell system; compressor etc.).**
- **Theoretical** **Semi-empirical**
- **Fixed time step** **Variable time step**
  - **ADVISOR runs @ fixed time steps.**
- **Fuel cell stack** **Fuel cell system**
- **Open source code** **Proprietary model**
  - **open model**

Virginia Tech Fuel Cell System Model

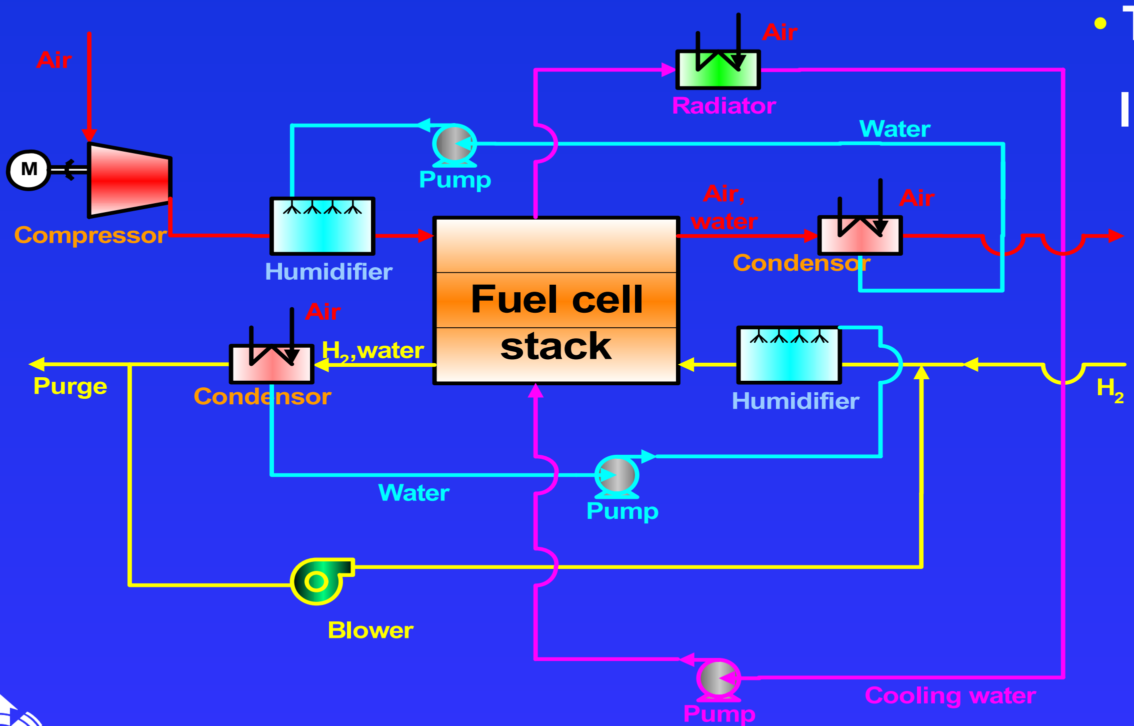
- A semi-empirical **transient, thermal** model for ADVISOR to evaluate:
    - –Hot & cold start vehicle fuel economy
    - –Power limitations due to temperature
    - –Water balance for reactant humidification
- Consists of a fuel cell stack & an auxiliary system
- Compressor data (map from Opcon Autorotor)



Royal Institute of Technology Fuel Cell System Model (KTH)

- Semi-empirical, steady-state
- Fuel cell stack & auxiliary system
- Compressor characteristics (maps from Opcon Autorotor)

- Detailed fuel cell model based on Springer *et al.* (1991)
- Re-circulation, purge
- Thermodynamic property library



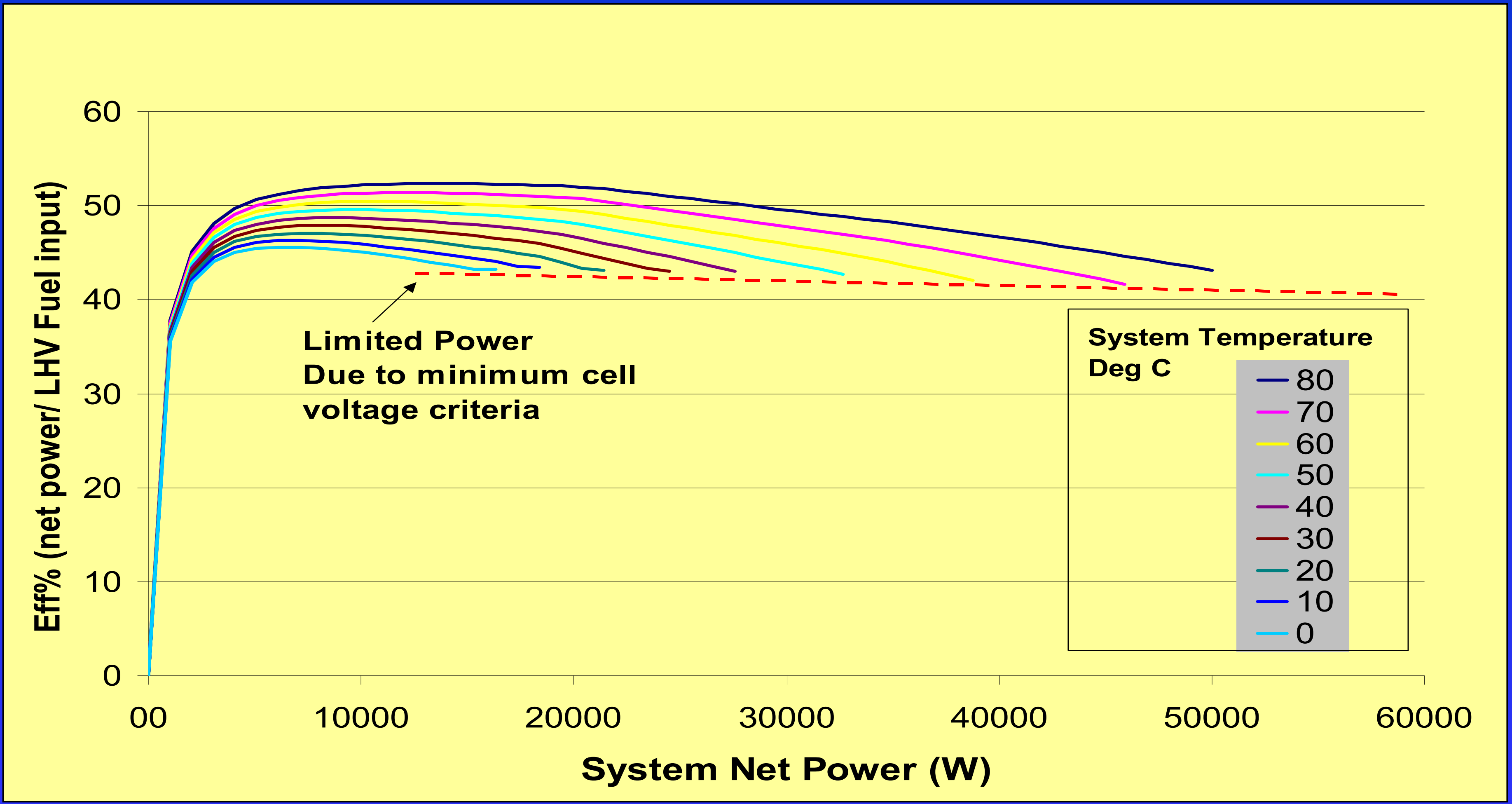
Comparison: VT & KTH Models

Model	Virginia Tech	KTH
Dimension	**0**	**0**
State **- Transient** **- Steady-state**	 √ **-**	 **-** √
System boundary **-Fuel cell** **-Stack** **-System**	 **-** √ √	 **-** √ √
Approach overall **-Theoretical** **-Semi-empirical**	 **-** √	 **-** √
Approach fuel cell **-Theoretical** **-Semi-empirical**	 **-** √	 √ **-**

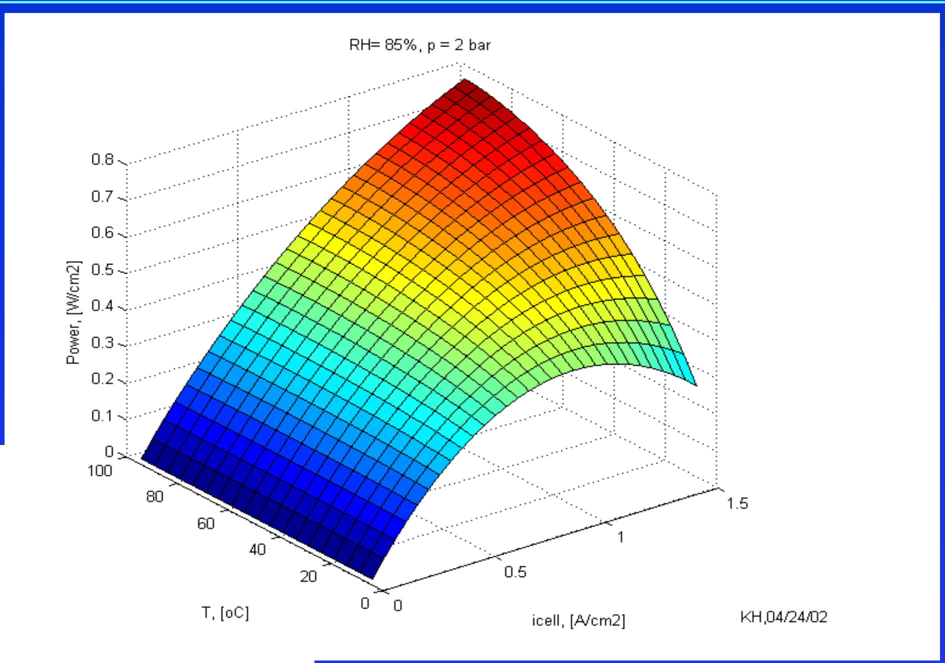
Comparison: VT & KTH Models

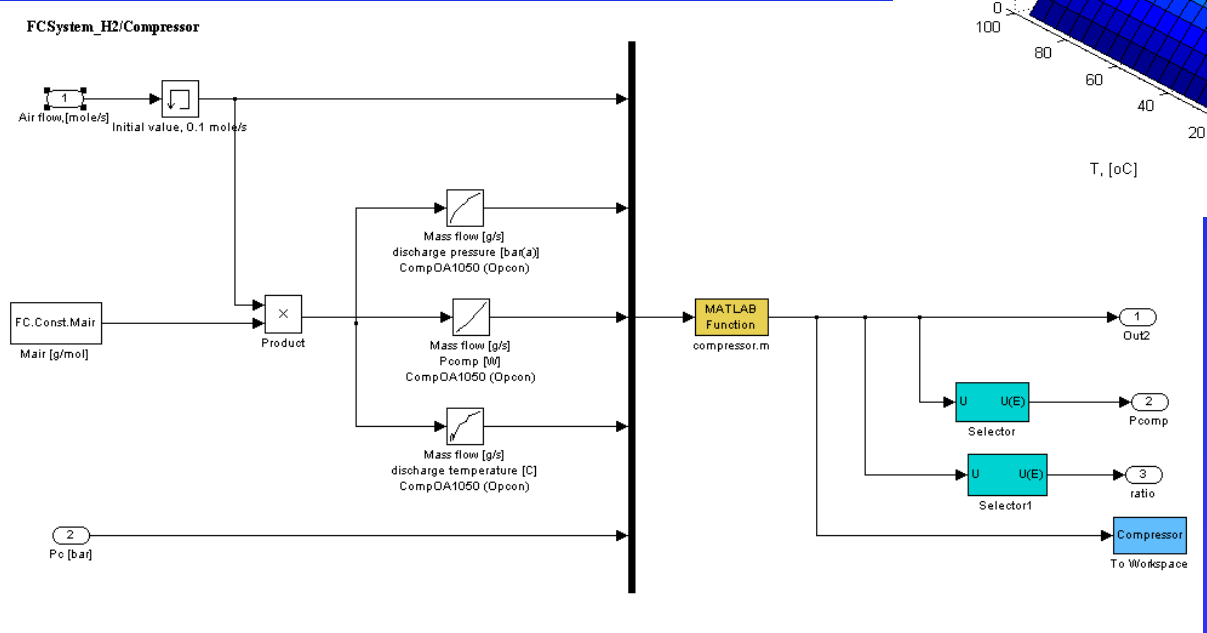
Model	Virginia Tech	KTH
Complexity -Fuel cell -System	Medium Medium/High	Medium/high Medium/high
Thermodynamics	√	√
Fluid dynamics	√	√
Environment	MATLAB/Simulink	MATLAB/Simulink
Speed -very fast -fast	√ -	- √
Fixed & variable time step	√	√
Flexibility	√	√

System Efficiency vs. Net Power

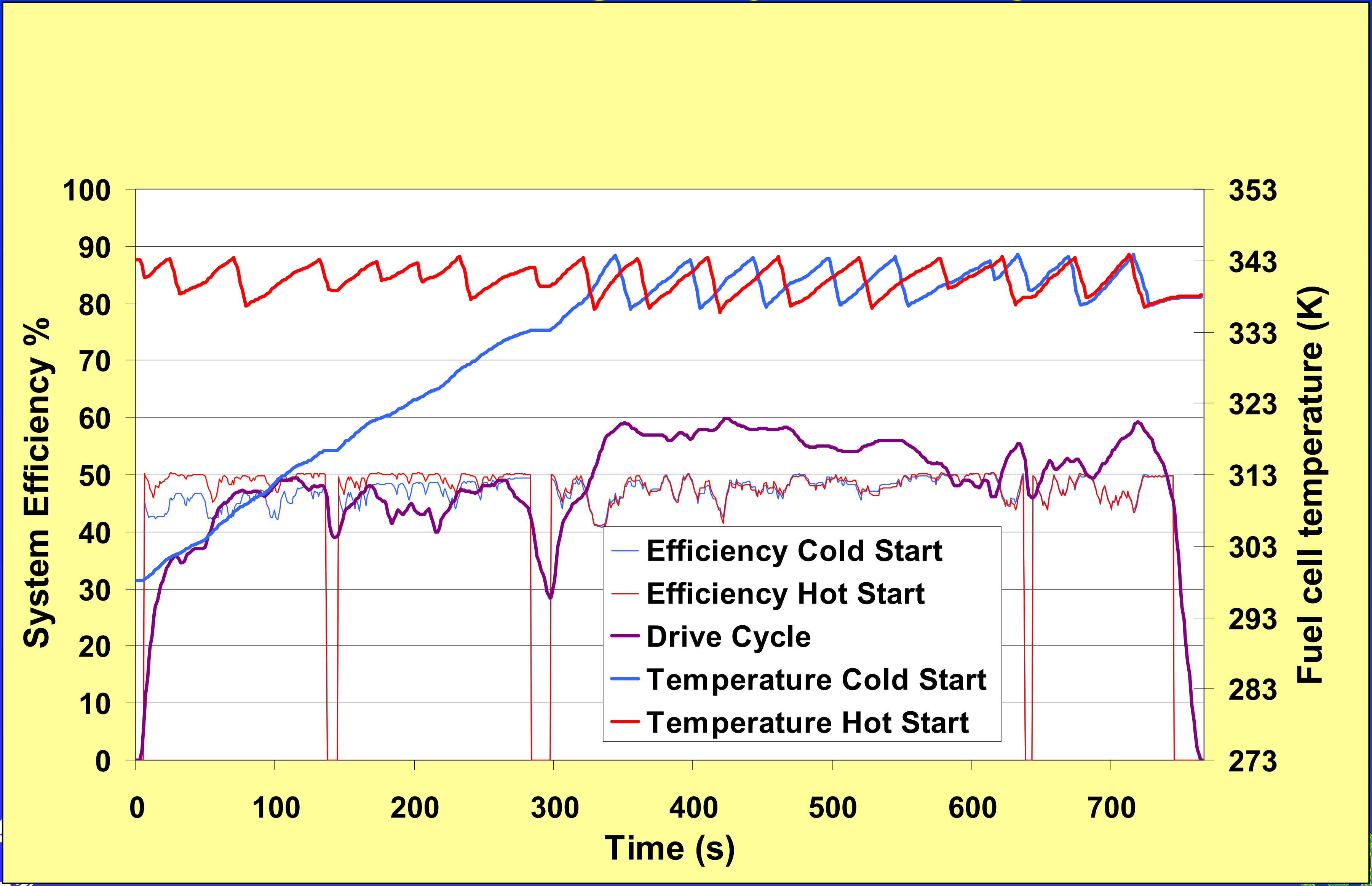


KTH Examples





Efficiency comparison between hot & cold start on a highway drive cycle



Concluding Remarks

- Initial decisions & evaluation criteria tools to help the user to find the fuel cell model for his/her needs
- VT & KTH fuel cell system models
  – Function well as stand-alone models and integrated into ADVISOR